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ELECTROMAGNETIC WAVE DIFFRACTION BY A DOUBLE-LAYER PERIODIC GRATING OF CURVILINEAR METAL STRIPS

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ABSTRACT

Reflection and transmission characteristics of double-layer two-periodic gratings of perfectly conducting infinite strips with a complex shape are considered. The structures with layers that have strips turned on 90 degrees and parallel are considered. The comparison of reflection properties of double-layer two-periodic gratings of straight-line strips with curvilinear ones is presented.

INTRODUCTION

Recently, new applications of periodic structures are very popular to design so-called electromagnetic crystals known also as photonic band gap (PBG) crystals for microwave devices. As a result, interest to two- and even one-dimensional periodic structures is renewed. Two-periodic plane strips structures are more attractive for application because of their possess resonance properties in the frequency band of single-wave regime due to a complex shape of the array elements and their very small thickness. The artificial electromagnetic crystals could find many applications for passive microwave devices such as filters, reflectors or antenna covers. The simple PBG crystals are made with only a few layers of periodic array. These multi-layered structures have of reflection or transmission frequency bands with sharp boundaries due to Febry-Perot effects.

The reflection properties of complex layered arrays of metal strips of C-, S- and Ω-shape placed in free space [1] and on dielectric substrates [2] were studied earlier. The main goal of this report is to study the reflected properties of two-layer periodic structures of curvilinear metal strips in free space. The element of grating is plane periodic metal strip having arbitrary shape on the grating period. The period of the grating is mach greater than its width. The width of the strip can change along the strip.

OPERATORS OF REFLECTION AND TRANSMISSION OF TWO-LAYER GRATING

Let's consider a system of two parallel gratings (Fig 1a). The parameter Δ is the distance between layers. Matrixes of the operators of reflection and transmission of the first and second gratings are written as $\hat{r}_1$, $\hat{t}_1$ and $\hat{r}_2$, $\hat{t}_2$. The amplitude of the partial waves between layers (Fig.1b) satisfy the following set of equations,

$$\begin{cases} \vec{A} = \hat{t}_1\vec{q} + \hat{r}_1 e\vec{B} \\ \vec{B} = \hat{r}_2\hat{e}\vec{A} \\ \hat{R}\,\vec{q} = \hat{r}_1\vec{q} + \hat{t}_1\hat{e}\vec{B} \\ \hat{T}\,\vec{q} = \hat{t}_2\hat{e}\vec{A} \end{cases}, \qquad (1)$$

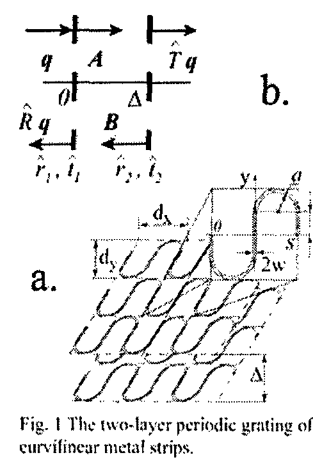

Fig. 1 The two-layer periodic grating of curvilinear metal strips.

where $\hat{e}$ is the plane-wave propagation operator in free space between the surface of layers. After the eliminating vectors of A and B from equations (1) we obtain the expressions for matrixes of reflection and transmission of two-layer grating,

$$\hat{R} = \hat{r}_1 + \hat{t}_1 \hat{e}\hat{r}_2 \hat{e}\left(\hat{I} - \hat{r}_1 \hat{e}\hat{r}_2 \hat{e}\right)^{-1}\hat{t}_1 ,$$

$$\hat{T} = \hat{t}_2 \hat{e}\left(\hat{I} - \hat{r}_1 \hat{e}\hat{r}_2 \hat{e}\right)^{-1}\hat{t}_1 ,$$

where $\hat{I}$ is the unit matrix. Numerical analysis below was carried out without taking in to account evanescent partial waves in the case of one-mode regime.

NUMERICAL RESULTS AND DISCUSSION

The scattering characteristics of two-layer arrays in free space for the cases of different strip shapes are presented and discussed bellow. Let us firstly pay attention to the frequency dependence of the reflection coefficients for a single array (Fig. 2). This is important for explanation the reflection properties of a two-layer structure. The reflection properties of single layer of curvilinear metal strips and all mathematical transformations have been considered in [3] more explicitly.

Now we consider the structure, which has identical layers when it is illuminated by E-polarized (along the x-axis) wave. The reflection coefficient of the straight strips is represented on Fig. 3. Coincidence of the data obtained by a rigorous numerical-analytical method described in [4] and the present method is good. The resonance of transmission due to interaction between the layers of the structure is observed of the frequency parameter $d_y / \lambda \approx 0.6$. A simple estimation of the interlayers resonant frequency can be made by considering the condition of equality of phases of the wave reflected by the structure's front boundary and the wave reflected by second layer taking into account a phase jump of wave propagated through a single array. The phase of the reflected by the first layer of the structure is $\psi_1 = arg\, r_1$. The phase of the wave reflected by the second layer at the plane of structure's front boundary is $\psi_2 = arg\, r_2 + 2(arg\, t_1 + \Delta k)$. One can expect that the maximum of reflection occurs when,

$$\psi_1 - \psi_2 = 2\pi l, \tag{2}$$

and it will be minimum if,

$$\psi_1 - \psi_2 = \pi(2l + 1), \tag{3}$$

where $l = 0, \pm 1, \pm 2, \ldots$. For a case of identical strips, if $\Delta = d_y / 2$ the requirement equation (3) becomes $2(arg\, t_1 + \pi\, d_y / \lambda) = \pi(2l + 1)$. At $arg\, t_1 = 0$, the minimum of a reflectivity would be observed at $d_y / \lambda = 0.5$ and for l=0, but as the $arg\, t_1 \neq 0$, the minimum is shifted to the greater frequencies. For the structure of wavy strips one more minimum generated by properties of the single layer is observed, except for a minimum of a reflectivity because of interaction between layers (Fig 4, curve 1). These two minimums practically coincide forming the band of almost total transmission, for structure of lines having the shape of rounded meander (Fig. 5, curve 1) . The band of reflection at near $d_y / \lambda \approx 0.8$ is generated by the complex shape of strips, but it is more widely and has more steep edges than in case of single layer.

If the structure consist from identical layers and the incident wave polarized along the y-direction (H-polarization) the grating of vary narrow straight strips do not reflect(Fig 3, curve 2). This effect looks like there is the incident wave simply does not see the grating. The change of the shape of strips leads to appearance of the band of reflection, which is more widely and has more steep edges (than in case of one layer) because interaction between layers. For structure of wavy strips this band is narrow than for the grating of strips with the shape of rounded meander narrow (Fig.4,5, curves 2), because of different magnitude of the quality factor of a resonance for single layer of such strips.

The dependence of the reflection coefficient upon polarization of the incident wave is observed, if there is identical orientation of strips in layers. This polarization influence is not desirable sometime. It is possible to decrease this dependence by rotation of the second layer on 90 degrees with respect to first one. Then the module of the reflection coefficient for normally incident waves polarized along axes of periodicity does not differ practically (curves 3 in a Fig. 3, 4. 5). If the polarization of the wave is arbitrary then the absolute value of the reflection coefficient remain about the same magnitude.

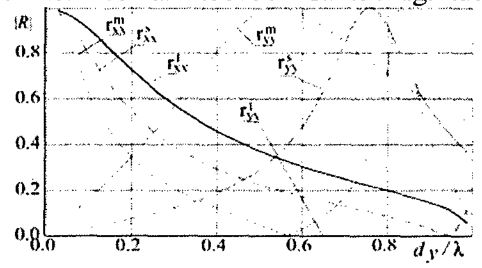

Fig. 2 Magnitudes of reflection coefficients of metal strips of variety shapes. 1 layer. $d_x=d_y$, $2w/d_y=0.05$, straight strips-superscript l, wavy line ($L_m=0$)- superscript s, the rounded meander with $L_m=0.2$- superscript m.

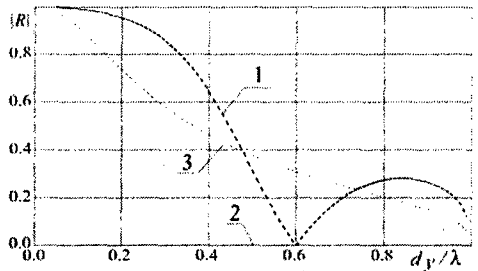

Fig3. Magnitudes of reflection coefficients of metal straight strips. 2 layer. $d_x=d_y$, $2w/d_y=0.05$, curve1 - E-polarization and identical layers, curve 2 - H-polarization and identical layers, curve 3 - layers that have crossed strips.

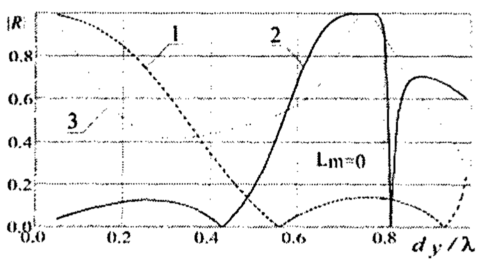

Fig4. Magnitudes of reflection coefficients of metal strips having the shape of wavy line , 2 layer. $d_x=d_y$, $2w/d_y=0.05$, curve1 - E-polarization and identical layers, curve 2 - H-polarization and identical layers, curve 3 - layers that have crossed strips..

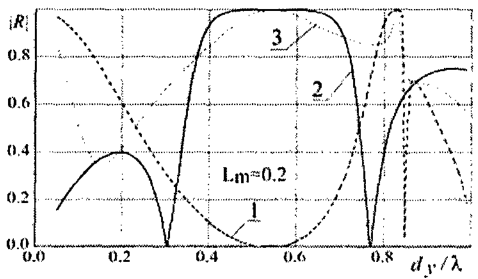

Fig5. Magnitudes of reflection coefficients of strips having the shape of rounded meander. 2 layer. $d_x=d_y$, $2w/d_y=0.05$, curve1 - E-polarization and identical layers, curve 2 - H-polarization and identical layers, curve 3 - layers that have crossed strips.

CONCLUSION

The electromagnetic scattering by two-layer periodic grating of curvilinear metal strips was considered. The numerical study for normal incidence wave shows the possibility of making resonant layers, polarization sensitive, having frequency bands of total reflection and transmission with very steep boundaries. In contrast to a single array, a layered structure offers the possibility to obtain sharp and wide filtering zones.

The author is grateful to S.L. Prosvirnin for the problem formulation and encouragement during the performance of this work.

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